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Analysis for Radionuclides in SRC and Coal Combustion Samples

Hittman Associates, Inc, Columbia, MD

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

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16. ABSTRACT The report deals with the determination of the levels of uranium, thorium, and their daughter products in coal, Solvent Refined Coal (SRC), coal flyash, and SRC flyash samples from Georgia Power Co.'s Plant Mitchell May and June 1977 combustion tests to compare the environmental emissions from the use of coal and SRC in the boilers. Gross alpha and beta activities were also measured. Uranium and thorium concentrations ranged from 0.8 to 39 ppm and 3.7 to 20 ppm, respectively. Calculated levels of other radionuclides in secular equilibrium with uranium and thorium ranged from 7.4 x 10 to the minus 17th power to 0.0001 ppm. Alpha levels could not be quantified due to the self absorption of the alpha particles. Beta levels, however, were on the order of 50 pCi/g. (A pCi is 10 to the minus 12th power curies; a curie is a basic unit for measurement of radioactivity, equalling 3.7 x 10 to the 16th power nuclear transformations per second.) Levels of radionuclides were also compared with reported levels of uranium and thorium in coal and SRC and with estimated emissions from coal-fired power plants. Uranium and thorium levels were of the same order of magnitude as those reported in the literature. Data from Plant Mitchell and other coal-fired power plants, as well as data obtained in this report, were used to estimate the level of uranium-238 that may be discharged from a power plant; the estimated level was 0.2 micrograms/cu m, which is below the allowable public use level.

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Coal	Thorium	Stationary Sources	21D	
Liquefaction	Fly Ash	Solvent Refined Coal	07D	
Combustion	Alpha Particles	Radionuclides	21B	20H
Industrial Processes	Beta Particles		13H	
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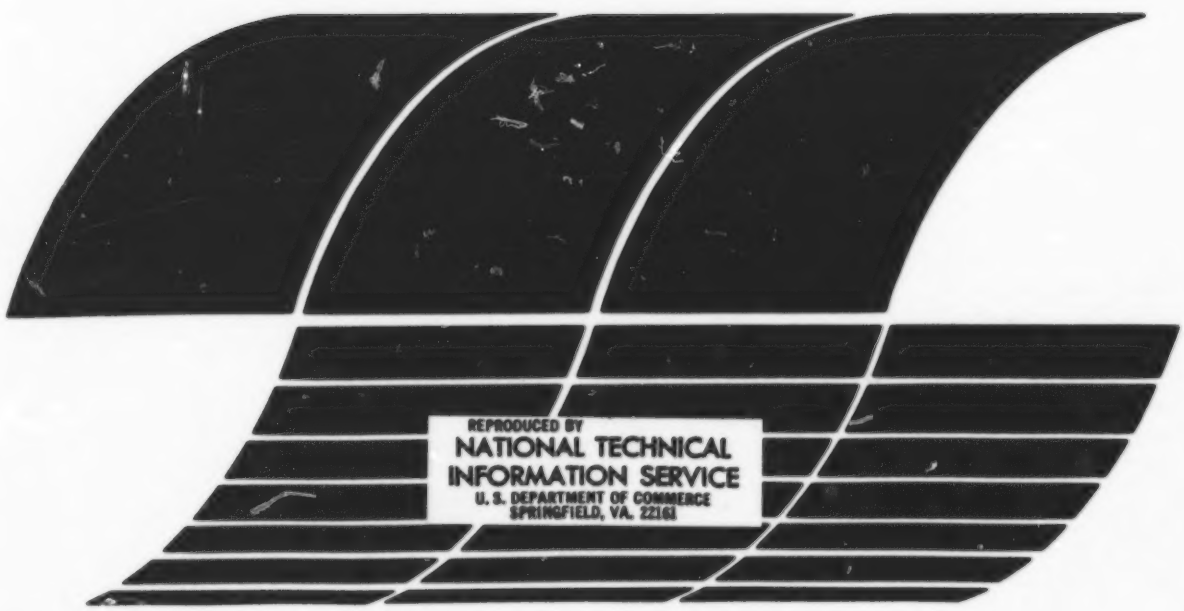

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by

Pamela A. Koester and Warren H. Zieger

Hittman Associates, Inc.
9190 Red Branch Road
Columbia, Maryland 21045

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EPA Project Officer: William J. Rhodes

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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TABLE OF CONTENTS

		Page
1.	SUMMARY	1
2.	INTRODUCTION	3
3.	SAMPLE COLLECTION AND ANALYSIS	6
4.	DATA ANALYSIS	10
5.	ESTIMATED RADIONUCLIDE EXPOSURE LEVELS	24
REFERENCES		27

1. SUMMARY

This report deals with the determination of the levels of uranium, thorium, and their daughter products in coal, SRC, coal flyash, and SRC flyash samples taken from Georgia Power Company's Plant Mitchell during the May and June 1977 combustion tests to compare the environmental emissions from the use of coal and SRC in the boilers. Gross alpha and beta activities were also measured in the samples.

Uranium and thorium were observed to be present at concentrations ranging from 0.8 to 39 ppm and 3.7 to 20 ppm, respectively. Calculated levels of other radionuclides in secular equilibrium with uranium and thorium were found to range from 7.4×10^{-17} ppm to 1.0×10^{-4} ppm. Quantitative alpha measurements could not be made due to the self absorption of the alpha particles in the samples. Beta measurements, however, could be taken and were found to be on the order of 50 pCi/gm. (A pCi is 10^{-12} curies. A curie is a basic unit for measurement of radioactivity, equaling 3.7×10^{10} nuclear transformations per second).

Levels of radionuclides in the samples were also compared with reported levels of uranium and thorium in coal and SRC and with estimated emissions from coal fired power plants. Uranium and thorium levels in the samples were found to be of the same order of magnitude as those reported in the literature. Data obtained from Plant Mitchell and other coal fired power plants, as well as data obtained in

this report, were used to estimate the level of uranium-238 which may be discharged from a power plant. The estimated level was found to be 0.2 $\mu g/m^3$ which is lower than allowed general public dose radiation levels of 7.0 $\mu g/m^3$. This leads one to conclude that the radionuclide levels present in the tested samples do not appear to pose any significant problem from a radiotoxic standpoint. Further analysis of various types of coal and SRC products is recommended, however, before this may be concluded on an overall basis.

2. INTRODUCTION

There are three major distinct chains of radioactive elements contained in essentially all coals: (1) the uranium series which originates with uranium-238; (2) the thorium series which originates with thorium-232; and (3) the actinium series which originates with uranium-235. These three elements decay into a number of radioactive species which are important from a radiotoxic standpoint. The decay process is a process of transformation of radioactive elements to other elements. This transformation is acompanied by emisson of alpha or beta particles and gamma radiation. When a radioactive element decays, a new radioactive element is born which itself is subject to decay. The uranium, thorium and actinium decay series are shown in Figure 1. Since the first member of each decay series has a relatively long half-life when compared to the other members, a steady-state condition is established which is known as "secular" equilibrium. This steady-state condition allows one to calculate the concentration of each of the daughter radionuclides. Those elements of most importance include thorium-230, radium-226, radon-222, lead-210, polonium-210, radium-228, thorium-228, and radon-220.

The concentrations of elements within these decay chains may vary significantly from one coal to the next. It has been observed that eastern coals generally contain about 1.6 ppm uranium and 2.0 ppm thorium although individual values may vary considerably (2). Western coals have been

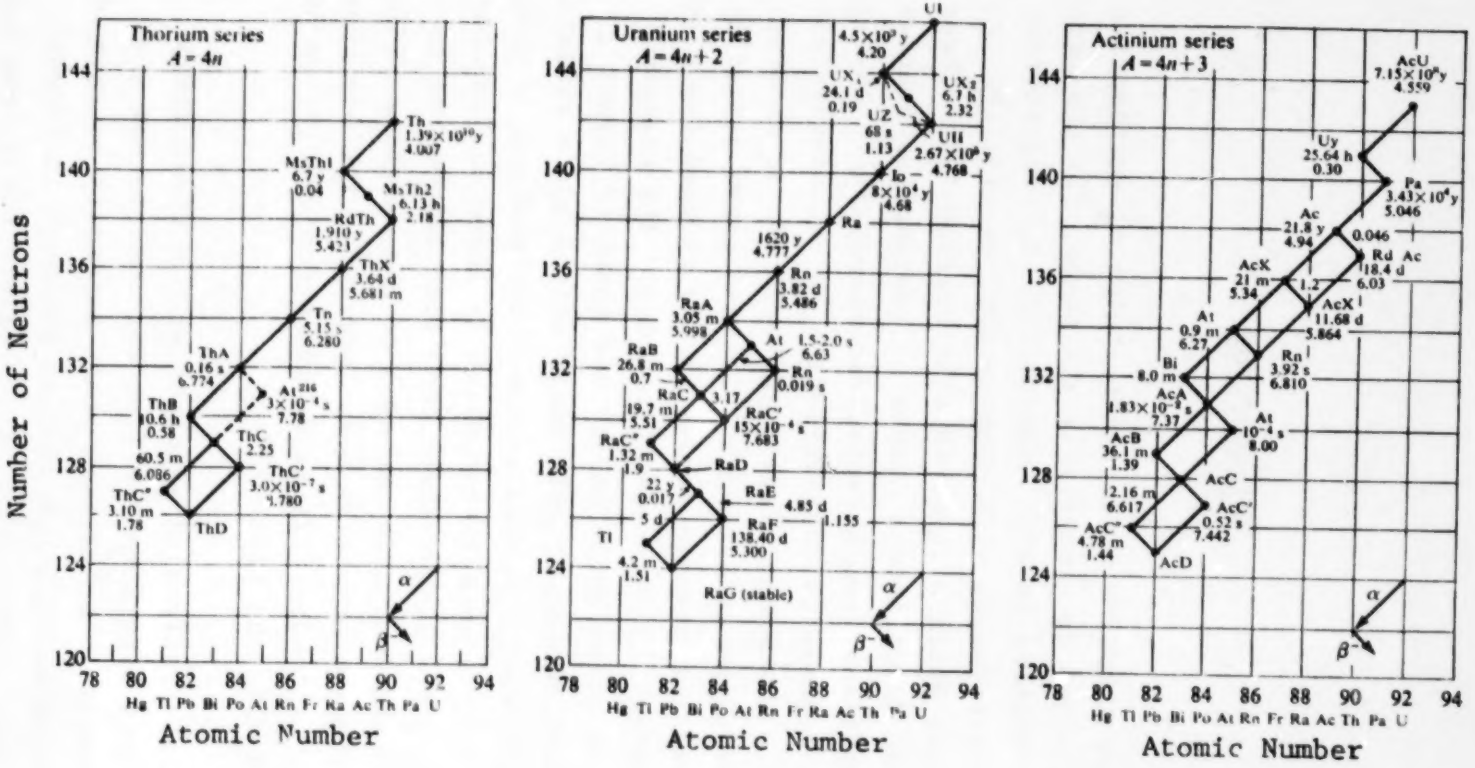

Figure 1. Radioactive Decay Chains (1)

reported to contain much higher concentrations ranging from 10 to greater than 5000 ppm (3). The concentrations of uranium-238, uranium-235 and thorium-232 naturally affect the levels of other radionuclides within the three chains as they are all considered to be in secular equilibrium with each element within their respective chains.

It has been observed in coal and SRC processing operations that radionuclides are most likely to be found in solid residues and flyash (4). Smaller quantities may be found in gaseous and liquid wastes. These operations tend to concentrate the radionuclides thereby possibly posing some occupational health hazards. This report examines the levels of several radionuclides in various coal and coal product samples and the significance of these levels from a radiotoxic standpoint. Also, the measurement of numerous radionuclides in the SRC samples is especially significant in view of the fact that the SRC samples were obtained from the first commercial coal fired facility ever to use SRC in a full scale comprehensive combustion test program.

3. SAMPLE COLLECTION AND ANALYSIS

3.1 Sample Collection

Samples were collected from combustion tests performed at Georgia Power Company's Plant Mitchell during the summer of 1977 (5). At this installation, both Kentucky coal and SRC solid fuel were individually burned in a pulverized coal-fired boiler to determine if SRC could replace coal as a primary fuel.

A Source Assessment Sampling System (SASS) train analysis was performed on the stack gases from the boilers. A typical train is shown in Figure 2. Samples analyzed for radionuclides in this report were taken from the 10-micron, 3-micron, and 1-micron cyclones, and from the filters of coal Run No. 1 on 5/25/77 and SRC Run No. 2 on 6/17/77. Two sets of coal, SRC solid fuel, coal particulate, and SRC particulate samples were analyzed.

3.2 Sample Preparation

In order to prepare the coal and SRC solid fuel samples for analysis, it was first necessary to pulverize and ash them to remove all available carbon. This step facilitated the subsequent sample digestion process. Coal and SRC particulate samples were also ashed and digested prior to analysis after a specific homogeneous mixture of particulate

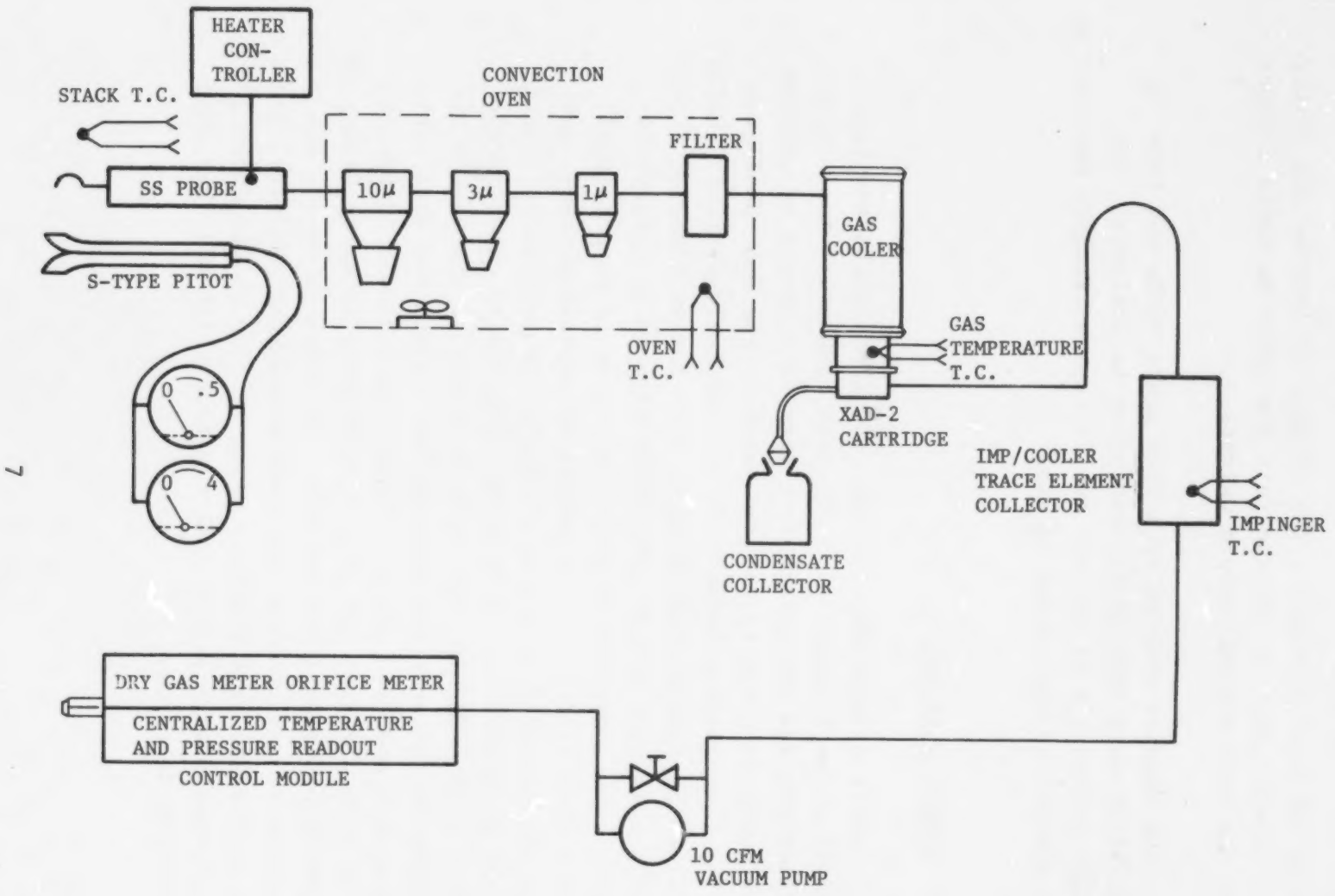

Figure 2. Source Assessment Sampling System (5)

matter had been obtained. The weights of cyclone and filter particulates used in the analysis are given in Table 1 along with the coal and SRC sample weights.

The samples used to determine gross alpha and beta activities were only pulverized prior to analysis. The weight percentage of cyclone and filter particulate matter was similar to that shown in Table 1.

3.3 Sample Analysis

Levels of uranium, thorium, and gross alpha and beta activities were measured in all coal, SRC solid fuel, coal particulate and SRC particulate samples. Levels of uranium were measured using techniques based on the U.S. Geological Survey Fluorimetric Methods of Uranium Analysis (15). Melts obtained by fusing uranium salts with sodium fluoride fluoresce a brilliant yellow green when exposed to ultraviolet light. The intensity of the fluoresence is proportional, within wide limits, to the amount of uranium present, and this relationship is the basis for the quantitative fluorimetric determination of uranium. A standard colorimetric test - ASTM D2333-68, was used to determine the levels of thorium in the selected samples (6). Alpha and beta activities were measured using a Baird Atomic Model 530 Spectrometer with a 2-inch gas flow proportional detector having an ultra-thin window (100 mg/cm^3). In order to detect the presence of any uranium and thorium daughter products, gamma ray activities were measured using a Baird Atomic Model 530 Spectrometer with a 1.75 inch x 2 inch thick NaI (TI) scintillation detector.

TABLE 1. WEIGHT DISTRIBUTION OF SAMPLES ANALYZED

(Grams)

Composite	10- Cyclone	3- Cyclone	1- Cyclone	Filters	Total
Coal Particulates					
#1	0.03750	0.29040	0.28090	0.05540	0.6641
#2	0.037385	0.29020	0.28100	0.05550	0.664085
SRC Particulates					
#1	0.5719	0.1902	0.0106	0.2312	1.0039
#2	0.5719	0.1901	0.0103	0.2294	1.0017
Coal					
#1	---	---	---	---	2.0036
#2	---	---	---	---	2.0051
SRC					
#1	---	---	---	---	2.0041
#2	---	---	---	---	2.0115

4. DATA ANALYSIS

4.1 Analyses by Fluorimetric Methods

4.1.1 Summary of Analyses

Table 2 lists the results of the uranium and thorium analyses. From these values, the concentrations of their daughter products were calculated assuming they are in secular equilibrium with their respective parent, and measured uranium is 99.27 percent uranium-238 (natural uranium contains this percentage of uranium-238). Calculated concentrations of uranium, thorium, and their daughter products of particular interest from a radiotoxic standpoint and/or with long half-lives are given in Table 3.

4.1.2 Discussion of Data

Several observations may be made based on the results of the laboratory analyses:

(1) Uranium levels were found to be less than thorium in all cases but the SRC particulates.

(2) Uranium and thorium were more concentrated in the SASS train particulate samples than in the coal and SRC solid fuel.

(3) The limited data do not allow one to predict any trends in the increase of uranium, thorium, and their daughter products in the particulate

TABLE 2. RADIONUCLIDE CONCENTRATIONS

(ppm by weight)

Source	Uranium	Thorium
Coal		
Sample #1	1.3	4.74
Sample #2	1.4	4.24
SRC		
Sample #1	0.8	4.99
Sample #2	1.3	3.73
Coal Particulates		
Sample #1	2.6	14.99
Sample #2	1.9	20.50
SRC Particulates		
Sample #1	39	11.46
Sample #2	28	9.48

TABLE 3. CALCULATED LEVELS OF RADIONUCLIDES IN COAL AND COAL PRODUCTS

(ppm by weight)

Product/Source	Coal	SRC	Coal Particulate	SRC Particulate
U^{238}	1.29-1.39	0.79-1.29	1.88-2.58	27.8-38.7
Th^{234}	$1.9\text{-}2.04\times10^{-11}$	$1.16\text{-}1.25\times10^{-11}$	$2.77\text{-}3.8\times10^{-11}$	$4.10\text{-}5.72\times10^{-11}$
U^{234}	$7.0\text{-}7.54\times10^{-5}$	$4.3\text{-}4.6\times10^{-5}$	$10.2\text{-}14\times10^{-5}$	$15\text{-}21\times10^{-5}$
Th^{230}	$2.1\text{-}2.3\times10^{-5}$	$1.3\text{-}1.4\times10^{-5}$	$3.0\text{-}4.2\times10^{-5}$	$4.5\text{-}6.3\times10^{-5}$
Ra^{226}	$4.4\text{-}4.7\times10^{-7}$	$2.7\text{-}2.9\times10^{-7}$	$6.4\text{-}8.8\times10^{-7}$	$9.5\text{-}13.3\times10^{-7}$
Rn^{222}	$2.8\text{-}3.0\times10^{-12}$	$1.7\text{-}1.85\times10^{-12}$	$4.1\text{-}5.6\times10^{-12}$	$6.0\text{-}8.4\times10^{-12}$
Bi^{210}	$3.4\text{-}3.7\times10^{-12}$	$2.3\text{-}2.44\times10^{-12}$	$5.4\text{-}7.4\times10^{-12}$	$8.0\text{-}11.1\times10^{-12}$
Po^{210}	$9.6\text{-}10.3\times10^{-11}$	$5.9\text{-}6.4\times10^{-11}$	$19.2\text{-}14.0\times10^{-11}$	$20.6\text{-}28.9\times10^{-11}$
Th^{232}	4.24-4.74	3.73-4.99	14.99-20.5	9.48-11.46
Ra^{228}	$1.73\text{-}1.94\times10^{-9}$	$1.7\text{-}2.99\times10^{-9}$	$6.9\text{-}9.3\times10^{-9}$	$4.4\text{-}5.3\times10^{-9}$
Th^{228}	$0.57\text{-}.64\times10^{-9}$	$0.56\text{-}0.75\times10^{-9}$	$2.3\text{-}3.0\times10^{-9}$	$1.4\text{-}1.7\times10^{-9}$
Ra^{224}	$2.8\text{-}3.2\times10^{-12}$	$2.8\text{-}3.8\times10^{-12}$	$11.5\text{-}15\times10^{-12}$	$7\text{-}8.5\times10^{-12}$
Rn^{220}	$5\text{-}5.7\times10^{-16}$	$5\text{-}6.8\times10^{-16}$	$20.7\text{-}27\times10^{-16}$	$12.6\text{-}15.3\times10^{-16}$
U^{235}	0.009-0.01	0.006-0.009	0.014-0.02	0.20-0.30
Th^{231}	$3.7\text{-}4.0\times10^{-13}$	$2.3\text{-}3.7\times10^{-13}$	$5.4\text{-}7.7\times10^{-13}$	$77\text{-}111\times10^{-13}$
$Pa^{239\text{-}231}$	$4.2\text{-}4.5\times10^{-6}$	$2.6\text{-}4.2\times10^{-6}$	$6.1\text{-}8.8\times10^{-6}$	$87\text{-}126\times10^{-6}$
Ac^{227}	$2.6\text{-}2.8\times10^{-9}$	$1.6\text{-}2.6\times10^{-9}$	$3.8\text{-}5.5\times10^{-9}$	$54\text{-}79\times10^{-9}$
Th^{227}	$6.1\text{-}6.5\times10^{-12}$	$3.8\text{-}6.1\times10^{-12}$	$8.9\text{-}12.8\times10^{-12}$	$126\text{-}185\times10^{-12}$
Ra^{223}	$3.7\text{-}4.0\times10^{-12}$	$2.4\text{-}3.7\times10^{-12}$	$5.5\text{-}8.0\times10^{-12}$	$78\text{-}115\times10^{-12}$
Pb^{211}	$1.14\text{-}1.23\times10^{-16}$	$0.74\text{-}1.14\times10^{-16}$	$1.7\text{-}2.5\times10^{-16}$	$24\text{-}35\times10^{-16}$

samples, whether the radionuclides are more heavily concentrated in SRC flyash as opposed to coal flyash, or what percentage of the radionuclides pass from coal to SRC since the coal is not known to be the same coal from which the SRC was produced. Literature has indicated, however, that at least 90 percent of the uranium is expected to be retained in the bottom ash and collected flyash (4).

4.1.3 Variation Within Data

Uranium levels were measured in duplicate samples by uranium fluorimetric analysis to determine whether the fluctuation between pairs of results was real or due to inadequacies in the method. The variance and standard deviation of the paired results were found to be 1.37 percent and 1.22 percent, respectively. This leads one to conclude that the differences in the reported values are not due to laboratory procedures but rather to nonhomogeneous samples. This is expected to be similar for the thorium results.

Efforts were also made to compare the observed levels of uranium and thorium in coal and SRC samples with those reported in the literature. Figures 3 and 4 give some indication of the wide range of uranium and thorium levels which may be found in coal. The data from the Eastern United States are plotted as unpatterned bars, those from the Illinois Basin as vertically striped bars, and those from the Western United States as horizontally striped bars. Table 4 provides reported data collected on levels of uranium and thorium in different types of samples.

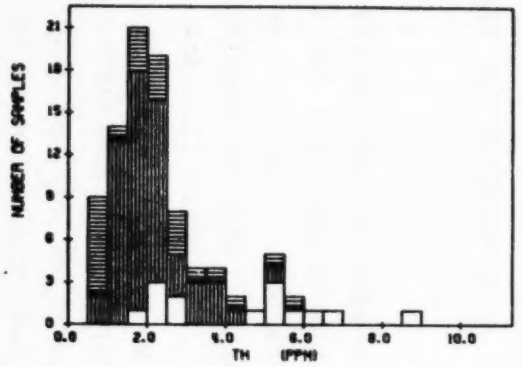

Figure 3. Distribution of Thorium in coals analyzed (7)

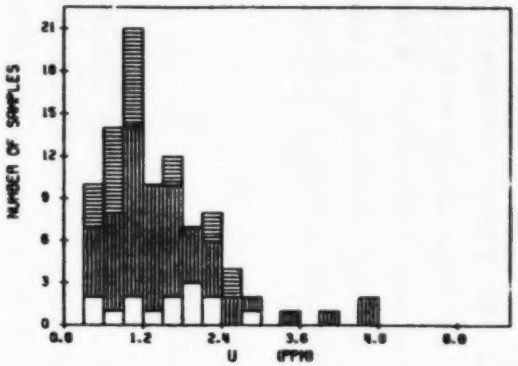

Figure 4. Distribution of Uranium in coals analyzed (7)

Note: Unpatterned bars - Eastern United States
Vertical striped bars - Illinois basin
Horizontal striped bars - Western United States

TABLE 4. LEVELS OF URANIUM AND THORIUM IN COAL AND RELATED PRODUCTS

(ppm by weight)

Location	Coal	Coal Flyash	Boiler Residue	Precipitator Collected Ash	SRC	Mineral Residue
Uranium						
Navajo Mines (4)[c]	2.56	--	--	--	--	--
Rocky Mt. Area (4)[c]	0.69	--	6.78	9.4	--	--
S. Illinois (4)[c]	2.18	--	14.9	30.1	--	--
Four Corners, NM (4)[c]	--	--	9.77	9.8	--	--
Illinois (8)[c]	1.1-4.2	--	--	--	--	--
General (9)[b]	1.41-1.53	11.6-11.9	--	--	--	--
Kentucky (10)[a]	1.1	--	--	--	0.54	.73
Thorium						
Kentucky (10)[c]	1.9	--	--	--	--	--
Illinois (8)[c]	3.1-8.0	--	--	--	--	--
General (9)[b]	3.0-6.5	26.1-30.4	--	--	0.19	10.0

[a]Neutron Activation Analysis

[b]Delayed Neutron Determination

[c]X-ray Fluorescence

The coal samples analyzed in this project originated from Kentucky while the SRC samples originated from the processing of Illinois coal. Average levels of uranium and thorium reported in the literature for Illinois coals are 1.5 and 2.1 ppm, respectively (7). Average levels of uranium and thorium reported for Kentucky coals are 1.85 and 2.6, respectively (7). The reported levels of these radionuclides are not significantly different between the two types of coal.

If we assume the coal samples contain approximately 10 percent ash and allow the variable "X" to represent the quantity of coal processed (in gm/day), then the quantities of uranium and thorium observed in the analyzed samples may be summarized as shown in Table 5.

TABLE 5. LEVELS OF URANIUM AND THORIUM IN COAL SAMPLES (ug/day)

Sample	Uranium	Thorium
Coal Sample 1	1.3X	4.74X
Coal Sample 2	1.4X	4.24X
Coal Sample 1 Particulates	0.03X	1.50X
Coal Sample 2 Particulates	0.02X	2.05X

For all samples, the quantities of uranium and thorium in the particulate samples were found to be lower than in the coal samples. This observation correlates well with the literature where it has been suggested that uranium and thorium are partitioned between the flyash, bottom ash, liquid streams, and, in the case of coal liquefaction processes, in the final SRC product.

If we assume the SRC to contain, on the average, 0.1 percent ash and allow the variable "Y" to represent the quantity of SRC combusted (in gm/day), then the quantities of uranium and thorium observed in the analyzed samples (in micrograms/day) may be summarized as shown in Table 6.

TABLE 6. LEVELS OF URANIUM AND THORIUM IN SRC SAMPLES (ug/day)

Sample	Uranium	Thorium
SRC Sample 1	0.8Y	4.99Y
SRC Sample 2	1.3Y	3.73Y
SRC Sample 1 Particulate	0.04Y	0.01Y
SRC Sample 2 Particulate	0.03Y	0.009Y

In all instances, the total quantity of uranium and thorium present in the particulate samples appears to be significantly less than the levels observed in the SRC samples. This leads one to conclude that the uranium and thorium is being partitioned more heavily into other process constituents.

Although this analysis appears to indicate that the total quantities of uranium and thorium are smaller in the flyash samples, the variable and limited data do not allow one to conclude that this is the general trend which should be observed in all cases. This is especially evident in view of the fact that bottom ash samples could not be analyzed to substantiate reported literature observations that 90 percent of the uranium and thorium should be retained in the bottom and flyash (4).

Assuming the following data for the combustion of SRC Run No. 2 on June 17, 1978 (data collected during plant visit).

Fuel Flow - 8,060 kg SRC/hr.

SASS Sample Volume - 28.5 m^3

Gas Flow - 3,620 m^3/minute

Weight of SRC particulates per sample volume - 1.0017 gm

Uranium concentrations in:

SRC - 1.3 ppm
SRC particulates - 28 ppm

Thorium concentrations in:

SRC - 3.7 ppm
SRC particulates - 9.5 ppm

$$\text{Weight of SRC Particulates/Hr} = 3620 \frac{m^3}{min} \times \frac{60 \text{ min}}{hr} \times \frac{1 \text{ Sample}}{28.5 \ m^3} \times \frac{1.0017 \text{ gm}}{1 \text{ sample}}$$

$$= 7634 \text{ gm/hr}$$

$$\text{Weight of Uranium in particulates} = 7634 \frac{\text{gm}}{\text{hr}} \times \frac{28}{1{,}000{,}000} = 0.214 \text{ gm/hr}$$

$$\text{Weight of Uranium in SRC feed} = 8{,}060{,}000 \frac{\text{gm}}{\text{hr}} \times \frac{1.3}{1{,}000{,}000} = 10.48 \text{ gm/hr}$$

$$\text{\% Uranium not in Particulates} = \frac{10.48 - 0.214}{10.48} \times 100 = 98$$

As shown above, the percentage of uranium not in the particulates was calculated to be approximately 98 percent of the total uranium in the SRC feed. Similar calculations for thorium show greater than 99 percent of total thorium not in the particulates. It is unfortunate that no samples were taken during the Plant Mitchell runs of the bottom ash. Therefore, there is no way to verify or refute this indicated bottom ash radioactivity concentration.

Table 7 lists the observed sample means ($\bar{x}$) and the means of the literature values (μ). On an absolute basis, the observed sample means correlate well with the means of the literature values and are of the same general order of magnitude.

4.2 Uranium Analysis by Atomic Absorption

Efforts to measure the levels of uranium in the samples were unsuccessful. Limits of detectability for uranium were found to be on the order of 50 ppm.

TABLE 7. EVALUATION OF SAMPLE DATA

(ppm by weight)

Source	Observed Data ($\bar{x}$)	Literature Data (μ)
Coal		
Uranium	1.4	1.0 (7)
Thorium	4.5	2.0 (7)
SRC		
Uranium	1.0	0.5 (10)
Thorium	4.4	0.2 (10)
Coal Particulates		
Uranium	2.2	11.8 (9)
Thorium	17.8	28.0 (9)
SRC Particulates		
Uranium	33.5	7.0 (10)
Thorium	10.5	10.0 (10)

4.3 Gross Alpha and Beta Activities

4.3.1 Summary of Analyses

Alpha and beta activities were measured in all the samples listed in Table 1. Radiation was qualitatively detected in all samples, but only quantitatively measured for the coal and SRC solid fuel particulate samples. Alpha radiation could not be determined due to self absorption of the alpha particles in the samples. Results of the beta analysis in coal and SRC particulate samples are given in Table 8. Expected levels of selected radionuclides are given in Table 9.

TABLE 8. BETA ACTIVITIES OF COAL AND SRC SAMPLES

Source	Weight (gm)	Activity (pCi)	Activity Concentration (pCi/gm)
Coal	1.945	BD	BD
Coal Flyash	0.678	17.2	25.0
SRC	1.842	BD	BD
SRC Flyash	0.208	12.3	59.0

BD = Below Detection

4.3.2 Discussion of Data

Photo-peak analysis was used in an attempt to confirm and identify the presence of uranium and thorium daughter products. The 239 KeV gamma ray of lead-212 (thorium-232 daughter) and the 609 KeV gamma ray of bismuth-214 (uranium-238 daughter) were selected because of their high

TABLE 9. EXPECTED RADIONUCLIDE ACTIVITIES

(pCi/gm)

Product/Source	Coal	SRC	Coal Particulates	SRC Particulates
U^{238}	0.004	0.002	0.006-0.008	0.008-0.012
Th^{234}	0.004	0.002	0.006-0.008	0.008-0.012
U^{234}	0.004	0.002	0.006-0.008	0.008-0.012
Th^{230}	0.004	0.002	0.006-0.008	0.008-0.012
Ra^{226}	0.004	0.002	0.006-0.008	0.008-0.012
Rn^{222}	0.004	0.002	0.006-0.008	0.008-0.012
Bi^{210}	0.004	0.002	0.006-0.008	0.008-0.012
Po^{210}	0.004	0.002	0.006-0.008	0.008-0.012
Th^{232}	0.004-0.005	0.004-0.005	0.017-0.023	0.011-0.013
Ra^{228}	0.004-0.005	0.004-0.005	0.017-0.023	0.011-0.013
Ra^{224}	0.004-0.005	0.004-0.005	0.017-0.023	0.011-0.013
Rn^{220}	0.004-0.005	0.004-0.005	0.017-0.023	0.011-0.013
U^{235}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06
Th^{231}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06
Pa^{231}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06
Ac^{227}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06
Th^{227}	0.002	0.001-0.002	0.003-0.004	0.04- 0.06
Ra^{223}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06
Pb^{211}	0.002	0.001-0.002	0.003-0.004	0.04 -0.06

yields. The spectrometer was set up to window in on these energies. Concentrations of these elements were too low to measure using this method. The low levels of radionuclides observed in these samples correlate with the calculated levels listed in Tables 3 and 4.

The summations of calculated beta radiation levels resulting from the presence of uranium, thorium, and their daughter products were found to be much lower than those recorded by the spectrometer. Possible explanations for this observation include: incorrect counting efficiency, interference from radionuclides other than those of specific interest, and levels of radiation being at the threshold of detection limits as was the case for the atomic absorption unit.

5. ESTIMATED RADIONUCLIDE EXPOSURE LEVELS

The levels of observed and calculated radiation appear to be quite small. To give some indication of their smallness, they may be compared to typical occupational and general public exposure levels given in Table 10 (3). The following assumptions, based on data obtained from Plant Mitchell and other typical coal fired power plants, were used to estimate the levels of uranium-238 expected to be discharged from a power plant which combusts SRC solid fuel.

(1) $\frac{\text{Stack gas particulates}}{\text{coal input}} = 8.42 \times 10^{-3}$ (11)

(2) Ash content of coal = 15.01% (11)

(3) Expected ash content of SRC = 0.1% (12)

(4) $\frac{\text{Stack gas particulates}}{\text{SRC input}} = \frac{0.1}{15.01} \; 8.42\text{x}10^{-3} = 5.6\text{x}10^{-5}$

(5) $\frac{\text{Stack gas}}{\text{coal input}} = \frac{\text{Stack gas}}{\text{SRC input}}$

= 183 scf/lb coal or SRC (avg) (13)

(6) SRC load = 17,600 lb/hr (Plant Mitchell tests) (14)

(7) $U^{238} = 0.9927 \; (U)$

TABLE 10. EXCERPTS FROM 10CFR20 STANDARDS FOR PROTECTION AGAINST RADIATION FOR MAJOR RADIONUCLIDES ASSOCIATED WITH COAL-BURNING FACILITIES

Element (Isotope)		"Occupational" Exposure Standard Air μCi/mℓ	Water μCi/mℓ	"General Public" Exposure Standard Air μCi/mℓ	Water μCi/mℓ	"Occupational" Exposure Standard Air μg/m^3	Water μmg/ℓ	"General Public" Exposure Standard Air μg/m^3	Water μmg/ℓ
Uranium Series									
Uranium (238)	S[1,2]	7×10^{-11}	1×10^{-3}	3×10^{-12}	4×10^{-5}	200	3×10^{3}	7	1.2×10^{2}
	I[1,1]	1×10^{-10}	1×10^{-3}	5×10^{-12}	4×10^{-5}	300	3×10^{3}	15	1.2×10^{2}
Thorium (234)	S	6×10^{-8}	5×10^{-11}	2×10^{-9}	2×10^{-5}	2.6×10^{-6}	2.2×10^{-8}	8.6×10^{-8}	8.6×10^{-10}
	I	3×10^{-8}	5×10^{-4}	1×10^{-9}	2×10^{-5}	1.3×10^{-6}	2.2×10^{-8}	4.3×10^{-8}	8.6×10^{-10}
Uranium (234)	S	6×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}	9.7×10^{-2}	1.5×10^{-1}	3.2×10^{-3}	4.8×10^{-3}
	I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}	1.6×10^{-2}	1.5×10^{-1}	6.5×10^{-4}	4.8×10^{-3}
Thorium (230)	S	2×10^{-12}	5×10^{-5}	8×10^{-14}	2×10^{-6}	1×10^{-4}	2.6×10^{-3}	4.1×10^{-6}	1×10^{-4}
	I	1×10^{-11}	9×10^{-4}	3×10^{-13}	3×10^{-5}	5×10^{-4}	4.6×10^{-2}	1.5×10^{-5}	1.5×10^{-3}
Radium (226)	S	3×10^{-11}	4×10^{-7}	3×10^{-12}	3×10^{-8}	3×10^{-5}	4×10^{-7}	3×10^{-6}	3×10^{-8}
	I	5×10^{-11}	9×10^{-4}	2×10^{-12}	3×10^{-5}	5×10^{-5}	9×10^{-4}	2×10^{-6}	1×10^{-5}
Radon (222)	S[3]	3×10^{-8}	--	3×10^{-9}	--	1.9×10^{-7}	--	1.9×10^{-8}	--
Lead (210)	S	1×10^{-10}	4×10^{-6}	4×10^{-12}	1×10^{-7}	1.2×10^{-6}	4.8×10^{-8}	4.8×10^{-8}	1.2×10^{-9}
	I	2×10^{-10}	5×10^{-3}	8×10^{-12}	2×10^{-4}	2.4×10^{-6}	6.0×10^{-5}	9.6×10^{-8}	2.3×10^{-6}
Bismuth (210)	S	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}	9	1.3	0.3	6.1×10^{-2}
	I	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}	9	1.3	0.3	6.1×10^{-2}
Polonium (210)	S	5×10^{-10}	2×10^{-5}	2×10^{-11}	7×10^{-7}	1.1×10^{-7}	4.4×10^{-9}	4.4×10^{-9}	1.6×10^{-10}
	I	2×10^{-10}	8×10^{-4}	7×10^{-12}	3×10^{-5}	4.4×10^{-8}	1.8×10^{-7}	1.5×10^{-9}	6.8×10^{-9}

(8) U = 33.5 μg/gm particulate SRC (data from this report)

$$U^{238} \text{ discharged} = \frac{(5.6\times10^{-5})(1.76\times10^{4})(33.5)(454)(0.9927)}{(183)(1.76\times10^{4})(0.028)}$$

$$U^{238} = 0.2 \ \mu g/m^3$$

This compares to the general standard of 7.0 $\mu g/m^3$ and is much less than an occupational exposure of 200 $\mu g/m^3$ shown in Table 10 for uranium-238. Since this analysis has not included dispersion in the atmosphere, the actual levels which should be observed would be significantly less than 0.2 $\mu g/m^3$. The conclusion that the levels of uranium, thorium, and their daughter products which may be discharged are quite small has also been reported by other authors (3). This may not be the case, however, for coals with very high uranium and thorium contents.

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